DEVELOPMENT OF A PROTOTYPE PORTABLE ADSORPTION UNIT FOR THE TREATMENT OF TOXIC CHEMICAL SPILLS

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- by -
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ABSTRACT

The use of Carbon Adsorption Technology for the development of a Prototype Portable Carbon Adsorption Unit was investigated. Carbon adsorption is a well-established treatment process. It is much safer and more economical in comparison with other conventional neutralisation techniques used for toxic chemical spill clean up. This thesis begins by examining the nature of toxic chemical spills, the effects on the environment and the economy, and the currently available response methods and treatment technologies. The discussion then continues into the use of Carbon Adsorption Technology for the treatment of toxic chemical spills. This is further developed by the conceptual design of a portable adsorption unit. Small scale column experiments were carried out in order to determine the flow configuration to be adopted by the unit. These experiments showed that an upflow configuration had greater potential to increase adsorption efficiency. From the conceptual design stage a full detailed design of the unit was done from which the unit was constructed. The constructed prototype portable adsorption unit was then evaluated by performing a series of adsorption experiments on a single column. The conclusion reached is that Carbon Adsorption Technology can be successfully applied on a small scale for the treatment of toxic chemical spills.

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INTRODUCTION

The pollution of the environment and safety and health risk to personnel due to accidental spills of agricultural and industrial toxic chemicals is frequent. For example, the New Zealand Fire Service attended 2151 and 2708 hazardous substance emergencies in 1990 and 1991 respectively (N.Z. Yearbook, 1990 & 1991). In New Zealand, toxic and hazardous substances may include pesticides, heavy metals, organic compounds and other substances, such as halogenated hydrocarbons and carbon monoxide.

Since New Zealand is basically an agricultural economy, the use of pesticides and herbicides is widespread. For example, up until mid 1988, 200 tonnes of Pentachlorophenol (P.C.P.) were used each year in New Zealand, mainly in protecting sawn timber from fungal attack. It was also used domestically - being available off the supermarket shelf for such things as moss and algae control, used by farmers for home treatment of timber, and industrially to control slime in pulp and paper production, in cooling waters, and in mushroom culture as a soil and timber steriliser.

The spillage of these chemicals during formulation, distribution and application occurs in small amounts, but the aggregate of these small amounts is substantial. A survey conducted by Pacific Basin Hazardous Research reported that there is substantial quantities of unmanaged agricultural waste in New Zealand. In fact, New Zealand keeps no official statistical record on the importation, production

or sales of pesticides (Stevenson, 1992). This waste is believed to be disposed of to municipal landfill sites. These landfills are typically not well-managed and offer little protection to nearby natural water, therefore, creating a health risk and causing destruction to aquatic life.

Often chemical spills are promptly diluted and flushed into effluent streams or dispersed into the environment. While being quick, easy and economical in the short term, the end result all to often ends in some form of environmental damage which generally results in very expensive redemption costs, for example, on average each U.S. Superfund site costs $US26 million to clean up (Stevenson, 1992).

There are several technologies available to deal with toxic chemical spills. Of these technologies carbon adsorption is a well-established treatment process. It is much safer and more economical in comparison with other conventional neutralisation techniques used for toxic spill cleanup. In fact, the Environmental Protection Agency in the United States of America maintains a very large adsorption unit for emergency cleaning of toxic chemical spills. Since the processing and application of toxic chemicals in New Zealand is on a much smaller scale and is so widely dispersed, a small scale adsorption unit was proposed as an ideal alternative to the management of toxic chemical spills.

1 CHEMICAL SPILLS, EFFECTS, RESPONSE METHODS AND TREATMENT TECHNOLOGIES

1.1 Definitions

Toxic and Hazardous Substances

Toxic and hazardous substances are defined as substances that have the potential to impair human, plant or animal health, or adversely affect the safety of the environment (Ward J.C. & Beanland R.). These substances exhibit one or more of the following properties (Code of Federal Regulations, 40 CFR Sub part C).

Corrosive	pH less than 2.0 or greater than 12.5.
Ignitable	Peusky-Martens Closed Cup Flash Point of less than 60°C.
Reactive	Thermal or mechanical or chemical reactivity.
Toxicity	Poisons, Carcinogens, Teratogens and Mutagens.

Substances exhibiting one or more of these properties are considered hazardous, and in the United States of America their treatment, storage and disposal are regulated by the Environmental Protection Agency.

Spillage

Spillage is defined as the loss of containment.

1.2 Causes of Toxic Hazardous Spills

The primary causes of hazardous substance spills can generally be fitted into one of five categories:

1) Spills resulting from rupture of or leakage from a storage or transporting container.

2) Spills resulting from the failure of storage, transfer, or transporting equipment.

3) Spills resulting from an in-plant or transportation accident.

4) Spills resulting from personnel error in loading or unloading operations or other improper handling.

5) Spills resulting from intentional events such as vandalism, sabotage, or deliberate release.

A private market survey was conducted by the Ansul Company in the United States to determine the frequency and average size of hazardous material spills in industry. From the 1800 responses from food and beverage industries to petroleum and petrochemical industries, the average spill size was determined to be 50.05 litres and the frequency of spills was determined to be 8 spills per plant per year. The locations in each plant where the spills occurred are illustrated in Table 1 below.

Table 1: Distribution of Spills in the Plant

Shipping	9%
Recovery	8%
Warehouse	11%
Manufacturing	30%
Process Piping	14%
Tank Storage	17%
Labs	10%
Off site transport	4%

The data clearly shows that the majority of spills occurs in the manufacturing process area.

1.3 Effects of Toxic and Hazardous Substance Spills

1.3.1 Introduction

Accidental spills of hazardous substances can result from a variety of causes including highway, rail, water and industrial plant upsets, the failure of retaining dikes, storm damage and malicious acts. The cost of returning the environment to an acceptable state after a spill can involve the expenditure of millions of dollars, yet undesirable effects may still remain for many months or years after the toxicants have been removed. The following outlines some of the impacts on the environment, wastewater treatment plants and the economy that can result from the spillage of hazardous substances.

1.3.2 Environmental Effects

The incorrect disposal or spillage of hazardous substances has the potential to impair the quality of either the hydrosphere, geosphere, atmosphere and biosphere, or all four at once simultaneously. This is illustrated in figure 1 below, which shows how pollutant species such as in a toxic chemical spill may be interchanged among the atmosphere, hydrosphere, geosphere and biosphere.

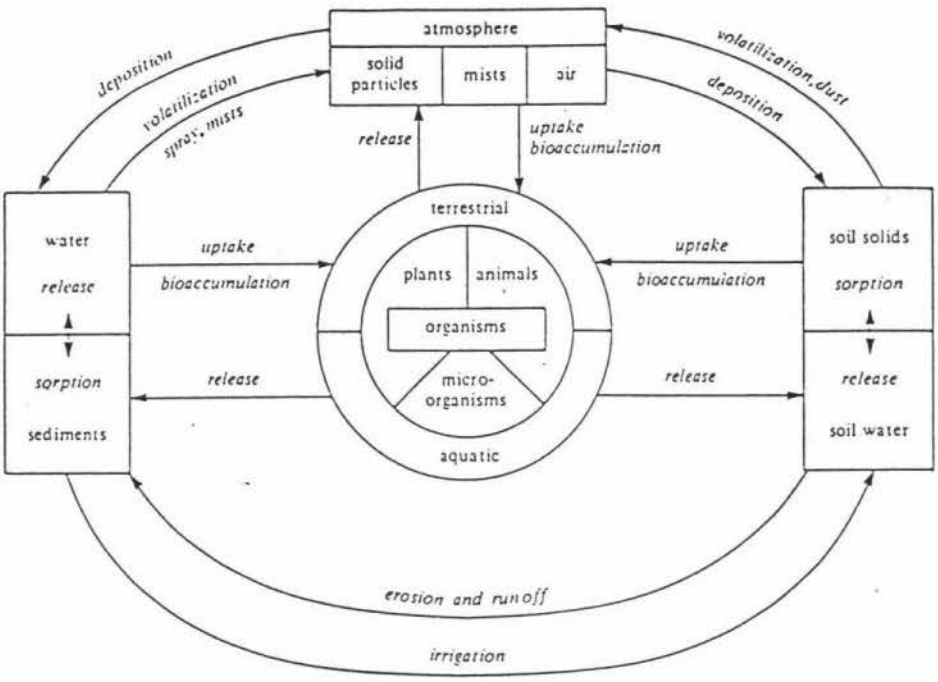

FIGURE 1. Interchange of Pollutant Species Among the Atmosphere, Hydrosphere, Geosphere and Biosphere

There are a number of environmental effects that can result from the spill of a toxic hazardous substance. The effects will depend on the volume and type of substance that is spilled. Usually the most environmental damage occurs immediately when a spill of hazardous materials reaches the aquatic environment. When a spill reaches the aquatic environment it can have the following effects:

1) destruction of all or part of the indigenous biota.

2) impairs the ecosystems function in a variety of ways such as destruction of habitat, elimination of organisms, and chemical and physical effects.

3) places the ecosystem in disequilibrium and this may be extended if persistent residual toxicants remain.

For these reasons it is desirable to prevent a spill from entering the aquatic environment.

Toxic substances may produce damaging effects in animals by absorption through external membranes, the ingestion of contaminated solids and fluids, or the inhalation of contaminated air. The result may be death or injuries, such as burns, impairment of neurological functions, or reductions in physiological processes. Spills of highly toxic hazardous substances produce shocks that quickly alter natural processes in the environment, consequently meeting with potential disastrous outcomes.

1.3.3 Effect of Spill Entry into Municipal Wastewater Treatment Plants

Ideally, untreated hazardous waste materials should not be allowed to enter wastewater treatment systems. However, the fact remains that hazardous materials do enter municipal wastewater treatment systems through illegal discharges or accidental spills. Federal studies in the U.S.A. have shown that

most hazardous wastes currently enter municipal wastewater treatment systems via industrial process-water streams (Bennett et al., 1982, pp4.3). Another common way in which hazardous materials enter wastewater treatment systems is from the flushing of spilled materials by emergency response units such as fire departments. This practice of flushing spills down sewer drains being a very common practice by the N.Z. Fire Service.

There are a number of adverse effects that result from hazardous substances entering municipal wastewater treatment plants.
These effects are as follows:

1) Flammable or toxic materials pose an explosive, as well as, health hazard within the treatment plant.

2) Materials can be corrosive and, therefore, damaging to the plant.

3) Biological processes, which are common in most treatment plants, can be upset due to shock loadings. Resulting in the reduction of removal efficiency, for example 200 mg/L of phenol is inhibitory to activated sludge.

4) Hazardous materials could pass straight through the plant, therefore violating water quality standards.

5) Hazardous substances can accumulate in the biomass and suspended solids, therefore creating a problem in the disposal of contaminated sludge.

As spills of hazardous substances are not planned, there is little forewarning of the impending problems that the wastewater treatment plant may face and, therefore, is greatly disadvantaged in being able to respond effectively.

1.3.4 Economic Effects

There are several major parameters that have been identified and quantified which affect the economic impact of hazardous substance spills. These factors have been identified as follows (Bennett et al., 1982, pp 4.27 - 4.28):

1) Number of discharges occuring annually.
2) Volume of the discharge.
3) Value of the product lost, less the value of the product recovered suitable for further commercial use.
4) Cost of retrieval and cleanup efforts, including cost of the mitigation chemicals used.
5) Loss due to the disruption of the production process.
6) Cost of equipment and property damaged and destroyed.
7) Cost of damage to non-plant property.

8) Cost of damage to the environment, including loss of commercial fishing and shell harvesting revenues.

9) Cost of compensation and/or injury to employees, including cost of lost time due to injury.

10) Cost of lost water usage, including industrial, municipal, agricultural, recreational, household, and drinking-water supply and aesthetic water uses.

The above factors only identify to a certain extent the economic impact of hazardous substance spills.

1.4 Response Methods to Spills

1.4.1 Introduction

There is a limitless variety of possible spill situations that may be encountered. For example, a spill may occur at an industrial plant during a processing or loading operation or in the field during the transit of materials. Facilities to respond to spills in industrial plants are generally more readily available than those in the field. Even though the best current design technology for chemical handling and containment equipment is implemented and operating and maintenance personnel are trained to minimise the likelihood of spill occurrences, accidental spills do occur. In many spill events, the quantity and toxicity of the spilled chemicals is great enough to cause catastrophic and

permanent biotic damage. For this reason it is essential that effective methodology to minimise spill damage be readily available. R.C. Scholz (1982) has identified three primary aspects of spill response:

-control at the source
-containment
-recovery and/or treatment

1.4.2 Control at the Source

Control at the source is the action taken to terminate the discharge of hazardous materials and to isolate already spilled materials to the immediate vicinity of the discharge point. Control of the discharge typically includes such actions as:

-righting an overturned and spilling container.
-pumping the contents of a leaking container into a different container.
-plugging a leak or closing a valve.
-changing the properties of the substance in the container.
(solidification, gelling, gasification or burning)
-chemical conversion of the substance in the damaged container.
-even stopping improper disposal activities.

It is very desirable to prevent the dispersion of a spill over and into soil and into ground water and surface water supplies. This being due to the fact that hazardous spills dispersed into soils and ground water are very expensive to treat and recover and the operation is also time consuming and often incomplete. In comparison control at the source can be effective and nearly complete, and can even lead to product recovery.

1.4.3 Containment

Containment of the spill involves limiting the dispersion of the spill to permit the recovery and treatment of the hazardous material. Containment methods may include the following: dikes, berms and dams; trenches; booms; barriers in soil; stream diversion; patching and plugging of containers or vessels; portable catch basins; over-packed drums or other forms of containerisation; and reorientation of the container. While there are many techniques for the containment of spills, only a few of these are discussed further.

1.4.3.1 Dikes, Berms and Dams

Dikes, berms and dams are typically used to contain spills on land or in water. Retention dikes and underflow dams may be used to contain floating insoluble materials; whereas dike usage is limited to either containment of an entire water body or development of a diversion pathway. Dikes, berms and dams are typically constructed from earth, sediment, gravel, coarse sand, or polyurethane.

1.4.3.2 Trenches

Trenches are often used as a first step to contain a spilled material prior to treatment. Trenches are effective and relatively inexpensive containment measures which can be used for land spills involving liquids and water spills involving insoluble sinkers.

1.4.3.3 Pumping

The pumping of spilled materials into a holding tank or any other container has shown to be most applicable to small spills of hazardous liquid materials on land (Unterberg et al., 1988, p162). The spilled material is typically diverted into a trench or some other type of excavation from which it is pumped into a container for further processing or disposal. Pumping is also very useful for the removal of accumulated pools of flammable material, therefore reducing the potential of a large fire, if ignited. Pumping has been used as a removal technique for water spills of both solid and liquid hazardous materials.

1.4.3.4 Dispersion/Dilution

Spills on land are generally diluted by means of water sprayed onto the spill. Diluting of land spills is primarily used to reduce the vapour hazards associated with the spill. The area around the spills should always be diked in order to prevent run-off from entering nearby waterways, sewers and stormwater

drains. Under no circumstances should a hazardous substance spill on land merely be dispersed by using water (Unterberg et al., 1988, p163).

Prior to the use of dispersion, careful examination of the specific spill situation and the potential toxic effects must be considered. Dispersion should not be considered as a first choice response method, especially in the case of spills into water. If other methods of containment and treatment are available, they should be used.

1.4.4 Recovery and/or Treatment

The efficiency and cost-effectiveness of recovery and treatment of spills primarily depends on the ability to contain the spill successfully. For effective treatments, it is necessary to contain the spill in as highly a concentrated form as possible. The treatment of spills can be broadly classified into two types:

1) those spills that require the removal of contaminants to a treatment system located at the spill where contaminants are detoxicified or reduced to safe levels.

2) those spills in which treatment is applied to the contaminants directly (in situ treatment). In situ treatment is often applied where containment of the spill is not possible.

There are a number of treatment systems used in the cleanup of spill sites. These systems are mobile and usually consist of modular equipment that can be easily brought onto a site. The technologies used in mobile treatment systems are discussed further in section 1.5 following.

1.4.5 Prioritising Chemical Spills

To be able to respond effectively to chemical spills, the use of statistical spill data is extremely useful for setting priorities and identifying project needs for spill prevention and preparedness. In 1980 the Canadian Environmental Emergencies Branch developed a spill priority list, with the main objective to identify the minimum number of chemicals that would account for the maximum number of spills. The list would be used to act as a focus for the development of countermeasures, analytical methods and spill manuals. This priority list has been recently updated to form the 1990 spill priority list which is shown in Table 2 overleaf.

Table 2: 1990 Chemical Spill Priority List

THE TOP 50 MATERIALS	
Acetic acid	nonylphenol
Aldrin	PCBs
Aminocarb	Pentachlorophenol
Ammonia	Perchloroethylene
Ammonium hydroxide	Phenol
Ammonium nitrate	Phosphamidon
Ammonium phosphates	Phosphoric acid
Ammonium sulfate	Phosphorus
Benzene	Potassium chloride
Calcium chloride	Propylene oxide
Calcium hydroxide	Sodium carbonate
Calcium hypochlorite	Sodium chlorate
Carbon tetrachloride	Sodium chloride
Chlorine	Sodium cyanide
Copper sulfate	Sodium hydroxide
Ethylbenzene	Styrene
Ethylene dichloride	Sulfur
Ethylene glycol	Sulfur dioxide
Ethylhexanol	Sulfuric acid
Fenitrothion	Tetraethyl lead
Ferric chloride	Toluene
Formaldehyde	Vinyl acetate
Hydrochloric acid	Xylene
Methyl alcohol	Zinc sulfate
Nitric acid	2,4-dichlorophenoxyacetic acid

The Chemical Spill Priority List was developed by taking all known spill priority lists, such as those published by the United States Environmental Protection Agency, The American Association of Rail Roads and The United States Coast Guard. Lists of material from the Transport of Dangerous Goods Act were also included. The list was reviewed and cut to form priority lists of the top 10, 25, 50, 150, 250 and 500 chemical spills (refer to Fingas, Stone, LeBlanc, Sergy et al., 1990). The chemicals are rated on the basis of spill number, spill volume, production volume, aquatic and mammalian toxicity. The utility of the spill priority list in terms of spill number, spill volume and chemical supply is given in figure 2.

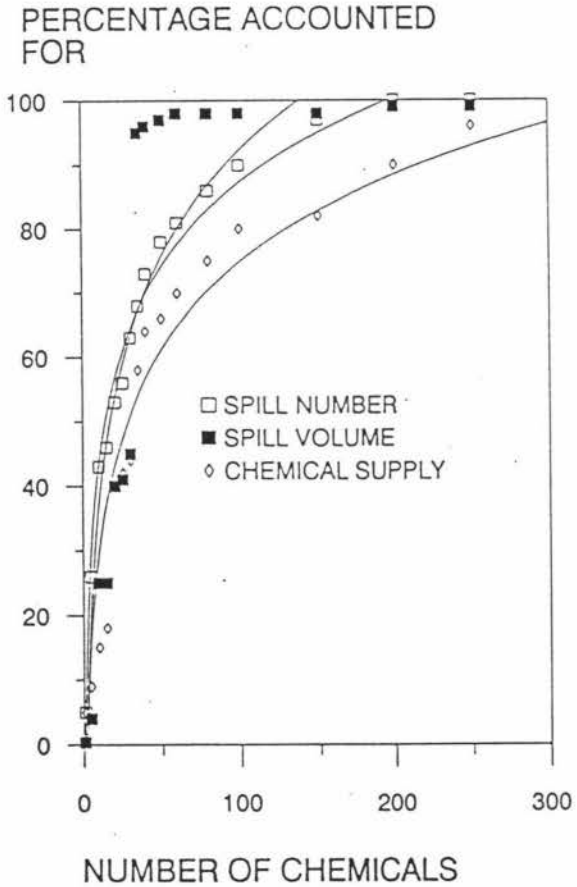

FIGURE 2. Utility of the 1990 Priority List

1.5 Mobile Treatment Technologies

Introduction

Mobile treatment technologies have been developed for emergency response and are used to contain, collect, and provide preliminary treatment of accidentally released hazardous materials and contaminated water. The Environmental Protection Agency (E.P.A.) in the United States of America has developed several types of mobile treatment systems for emergency response of which some have been used in the cleanup of Superfund sites. They usually consist of modular equipment that can be brought on site by truck or railcar. Some of these mobile treatment technologies are discussed further in this chapter.

1.5.1 Biological Treatment Technologies

There are a number of biological treatment technologies existing for the treatment of aqueous waste streams contaminated at low to moderate levels with non-halogenated organics and some halogenated organics.

The basic processes available are:

1) *Aerobic biological treatment*:

a tank based process using oxygen metabolising organisms and careful process control for low-strength aqueous waste streams contaminated with low levels of non-halogenated organics and/or certain halogenated organics.

2) *Anaerobic biological treatment*:

a tank based process using micro-organisms capable of chemical biodegradation in the absence of oxygen. Careful process control and extended retention time is required.

3) I*n situ biodegradation*:

use of existing indigenous aerobic bacteria, or, introduced cultured strains in soil. Activity is often accelerated with the addition of nutrients. Biodegradation of organics in soil or ground water may require 6 to 18 months.

Rationale for Biological Treatment:

1) Bacteria are natural components of ecological systems. Their use as a countermeasure ensures that foreign material is not introduced.

2) Bacteria will metabolise organic hazardous materials to the principal end products carbon dioxide and water according to the general equation:

$$C_x H_y O_z + O_2 \Longrightarrow CO_2 + H_2O$$

Biological treatment measures may be employed in one of two ways:

1) in situ to a spill of hazardous material, this is, in the receiving water itself,

2) by pumping the toxic spill to a mobile biological treatment system brought to the spill site.

For either treatment system the amount and nature of the toxic chemical spill needs to be determined so that the appropriate bacteria may be used and the proper amount of bacterial culture applied. Once the nature and amount of hazardous material spilled have been determined, and once containment has been achieved or at least ambient concentration determined, the bacterial treatment measures may be deployed.

1.5.2 Chemical Treatment Technologies

1.5.2.1 Neutralisation

Neutralisation is the interaction of an acid or a base to adjust the pH of a mixture or solution to between 5 and 9. It can be used as either a final waste treatment process, or as a pretreatment process to prepare a waste stream for further treatment. Acid spills are typically neutralised by using lime, limestone or sodium hydroxide, and alkaline spills by either HCL and in some cases H_2SO_4. The quantity and concentration of the neutralising reagent used depends on the influent and the desired pH of the effluent. Equipment used in a mobile neutralisation treatment system typically consists of a chemical feed system and a rapid mixing process, followed by another physical/chemical process for by-product removal as required.

Waste Streams Treated :

Neutralisation is typically used on liquids, but can also be used to treat the following wastes:

-Organic and inorganic waste streams

-Spent acid and alkali wastes

-Sludges, slurries and gases

Disadvantages:

-spent acid and alkali wastes with pH between 4.0 and 9.0 may not be treated effectively by neutralisation.

-solids and sludges may require large dosages of chemicals, due to the difficulty of achieving complete mixing and the potentially high buffer capacity of solid phases.

-toxic gases, such as ammonia and hydrogen cyanide may be released if wastes are not mixed slowly and are not properly prepared.

-heavy metals may be precipitated out from the solution and result in significant quantities of sludge.

-chemical complexes may not be effectively removed during further processing.

-additional processing of sludges may be required due to regulatory requirements for disposal of sludges.

1.5.2.2 Precipitation

Precipitation is the physical/chemical process in which dissolved chemical species in solution, for example, metals, are transformed into solid phases for removal. The chemical equilibrium relationships between the soluble substances are generally altered by the addition of chemicals, such as lime and sodium sulphate. Additional chemicals are sometimes required to adjust the pH of the mixture, since the solubility of the metal hydroxide and sulphides is very dependent on pH. The equipment required for precipitation include:

-Reaction tank with rapid mixing
-Chemical storage tanks
-Chemical feed pumps
-pH controls
-Clarifiers, filters and centrifuges may be required for the dewatering of sludges

Waste Streams Treated:

Precipitation is well suited for detoxifying aqueous solutions containing heavy metals and suspended solids. Waste waters contaminated with heavy metals are typically treated using precipitation. The heavy metals include:

-Arsenic	-Lead
-Cadmium	-Manganese
-Chromium	-Mercury
-Copper	-Nickel
-Iron	-Zinc

Disadvantages:

-organic compounds can interfere with precipitation by forming organometallic complexes.

-each metal salt has a different optimum pH for maximum removal and precipitation.

1.5.2.3 Dechlorination

Dechlorination is a process whereby chlorine is chemically removed from chlorinated organic compounds, such as P.C.B.s and dioxins. The treatment system uses a sodium-based reagent composed of an alkali metal and polyethylene glycol. Dechlorination is achieved by nucleophillic displacement of chlorine atoms by polyethylene glycol, to form an alkali metal chloride (typically KCl or NaCl) and a substituted organic polymer. By-products of the dechlorination process include chloride salts, polymers, and sometimes even heavy metals.

The equipment required for a dechlorination system is as follows:

-Reaction vessel

-Mixing chambers

-Reagent storage tanks

-Chemical feed pumps

-Dual filter beds

-Vacuum degasser

Waste Streams Treated:

Portable dechlorination treatment systems have been limited to the treatment of P.C.B. contaminated transformer fluids (organic fluids). Chlorinated acids and thiols have also been chlorinated by this process.

Disadvantages:

-the process should take place in a nitrogen atmosphere due to the reagents being air and water sensitive.

-moisture content adversely affects the rates of reaction and dewatering should be a pre-treatment step.

-contaminant concentration is a limiting factor. For example, P.C.B. concentrations exceeding 5,000 ppm cannot be treated cost effectively, due to excessive sodium requirements.

1.5.3 Physical Treatment Technologies

Physical treatment processes separate the waste stream by either applying physical forces or changing the physical form of the waste. In either case the chemical structure of the substance in the waste stream remains the same. Physical processes are usually simple, relatively inexpensive and can be applied to a wide range of wastes.

1.5.3.1 Air Stripping

Air stripping is a process, by which dissolved molecules are transferred from a liquid into a flowing gas. The driving force for mass transfer is provided by the concentration gradient between the liquid and gas phases, with solute molecules moving from the liquid to the gas until equilibrium is reached. When the process is applied to hazardous waste treatment it is primarily used to remove relatively volatile dissolved organic contaminants, such as toluene and trichloroethylene from water or aqueous waste. Air stripping has been successfully used in the cleanup of ground waters contaminated with low levels of volatile solvents (Byers & Morton, 1985). Air stripping has also been used for the removal of volatiles from industrial aqueous wastes containing traces of dissolved solvents.

Air stripping is most efficiently carried out in a packed tower with a countercurrent flow of air and water. Contaminated water is pumped to the top of the tower and distributed uniformly across the packing. It flows downward in a film layer along the packaging surfaces. Air is blown into the base of the tower and flows upwards, contacting the water. Packed-tower operation provides a high level of turbulence and a very large surface area for mass transfer. Volatile organics are transferred from the water to the air and carried out the top of the tower. Packed towers in portable systems are typically constructed out of fibre reinforced plastic making them lightweight and structurally sound.

Disadvantages:

-limited only to dilute liquid aqueous wastes with volatile organic concentrations less than approximately 100 mg/ L (Freeman et al., 1989).

-suspended solids in the waste stream should be removed prior to air stripping.

-the process effectively converts a water pollution problem to an air pollution problem, as the gas leaving the top of the tower contains all toxic volatile organic compounds removed from the waste water stream. Therefore, air pollution controls are sometimes required.

1.5.3.2 Ion Exchange

The process of Ion Exchange involves the removal of anions and cations dissolved in a dilute aqueous waste. Ions are held by electrostatic forces to functional groups on the surface of a solid and are exchanged for ions of a different species in solution. The exchange takes place on a synthetic resin. Various types of resins are available, including weakly and strongly acidic cationic exchangers and weakly and strongly basic anion exchangers.

A significant feature of ion exchange is that it has the ability to separate, or purify, as well as concentrate pollutants. Some exchangers are selective for certain metals and can remove low concentrations of toxic metals, such as sodium or calcium. Ion exchange can also be used in some applications to purify a spent chemical concentrate by removal of low-level contamination.

To date the greatest use of ion exchange has been in the treatment of inorganic wastes. This has been mainly due to the fact that standard exchangers exhibit unfavourable kinetics of sorption for organic species from liquids non-polar in character and because the molecular weight of many organics is too high to permit ion exchange at practical rates in polar solutions. Ion exchange is an external treatment process in which the spilled material is pumped through a column containing an appropriate resin.

Disadvantages:

-chemical wastes are produced if excess regenerant is required.

-there are limitations on the concentration of what can be treated and produced.

-down-time is required for regeneration.

-resins cannot yet be made which are specific to a particular substance.

-ion exchange resins are prone to fouling by some organic substances.

1.5.3.3 Membrane Separation

There are a number of membrane separation technologies available. These include reverse osmosis, hyperfiltration, ultrafiltration and electrodialysis. Membrane technologies separate solutes or contaminants from liquids through the use of semi-permeable membranes. These semi-permeable membranes function by selectively rejecting contaminants based on pore size, ion valence or co-precipitation. To date reverse osmosis is the only membrane technology that has been used as a mobile system.

The reverse osmosis system allows a solvent such as water to be removed from a solution containing solutes by the application of a pressure driven membrane process. During the process solvent molecules (water) are forced through the microscopic pores of the semi-permeable membrane by achieving sufficient hydrostatic pressure to overcome the concentrate osmotic pressure. As the solvent flows through the membrane, the larger organic and inorganic compounds are rejected. The effectiveness of a reverse osmosis system depends on the following:

-temperature of the solution
-pressure of the system
-pH of the solution
-chemical and ohysical structure of the membrane

Waste Streams Treated:

Reverse osmosis has been used in effectively treating the following:

-P.C.B.s and chlorinated organics in groundwater
-Waters with high BOD levels present
-Insecticides/herbicides in groundwater
-Organic and inorganic leachate

Disadvantages:

-suspended solids and oils must be removed to avoid fouling of the membrane.

-process residuals which include solutes that remain in the effluent in the range of 10 - 100 ug/L, and concentrate solution (10-20 % of feed volume).

1.5.4 Activated Carbon Adsorption

Activated carbon adsorption is one of the most frequently applied technologies for the removal of trace organic compounds from an aqueous solution. In the adsorption process, molecules attach themselves to the solid surface through attractive forces between the adsorbent and the molecules in solution.

Activated carbon will adsorb most organic compounds to some degree. Factors that affect the adsorption process include:

-Carbon pore structure
-Carbon contact time
-Temperature
-pH

Waste Streams Treated:

Carbon adsorption can be applied to a wide range of waste streams containing organic compounds. Classes of organic compounds amenable to adsorption on activated carbon are given in Table 3 below.

Table 3. Classes of Organic Compounds Amenable to Adsorption on Activated Carbon

Aromatic solvents	Benzene, Toluene, xylene
Polynuclear aromatics	Naphthalene, Buphenyls
Chlorinated aromatics	Chlorobenzene, PCBs, Aldrin, Endrin, toxaphene, DDT
Phenolics	Phenol, cresol, resorcinol
High-molecular weight aliphatic amines and aromatic amines	Aniline, toluene diamine
Surfactants	Alkyl benze sulfonates
Soluble organic dyes	Methylene blue, textile dyes
Fuels	Gasoline, kerosene, oil
Chlorinated solvents	Carbon tetrachloride, perchloroethylene
Aliphatic and aromatic acids	Tar acids, benzoic acids

(O'Brien et al., 1983)

Disadvantages:

Waste streams with low molecular weights, high polarities and high solubility do not readily adsorb on to activated carbon. Activated carbon adsorption is also not recommended for waste streams containing a high solids content (greater than 500mg/L), unassociated metals and high humidity gas streams.